8.—Further recoveries of two impact-fragmented Western Australian meteorites, Haig and Mount Egerton

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Abstract

The site of find of the Haig octahedrite iron meteorite has been revisited, an impact pit of unusual type recognised 183 m distant, and 23.3 kg of fragments recovered. Consideration of the pit, distribution of material, and its impact damage, enable a reconstruction of the circumstances of fall and fragmentation. The mineralogy is briefly noted.

The site of the unique Mount Egerton meteorite has been relocated. More than 3000 fragments resulting from severe impact fragmentation and weighing 27 kg have been recovered. The morphology of the material is described and the proportions of enstatite and metal assessed. The meteorite is grouped with Shallowater as an unbrecciated, metal-bearing (21%) enstatite achondrite.

THE HAIG METEORITE

Introduction

The main mass of the Haig octahedrite iron weighing c. 480 kg was discovered in 1951 by A. J. and H. E. Carlisle, who later donated it to the Western Australian Museum. The site of find (Fig. 1) is nearer to Rawlinna than to Haig and has approximate coordinates 31° 23' S., 125° 38' E.

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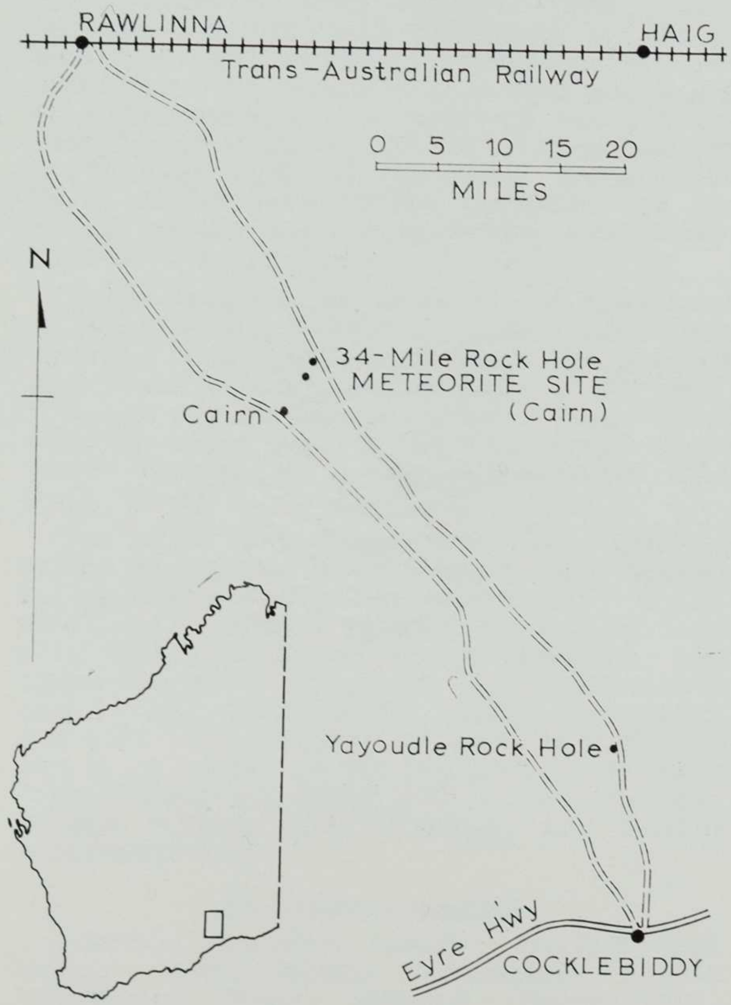

Figure 1.—Location of Haig meteorite recovery.

In 1965, A. J. Carlisle guided M. K. Quartermaine and the writer to the site to seek fragments whose existence had been predicted from fracture scars on the main mass. During the search, Mr. Carlisle noted a shallow pit 183 m south of the site with limestone fragments of sub-travertine type on its northern side. Correctly interpreting this inconspicuous pit as of impact origin (though the area abounds with sink holes and allied features), he walked the line towards the site of the main mass and found the major fragment of 22.88 kg almost immediately. Minor fragments were also recovered, and the pit was later excavated.

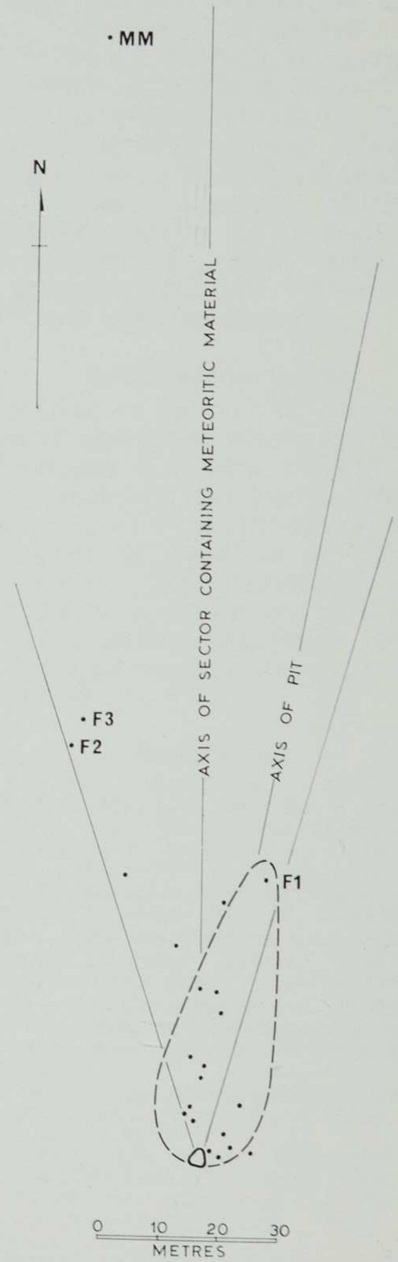

Figure 2.—Field distribution of the main mass (MM), major fragments (F1-F3), and minor fragments (indicated by dots) of the Haig meteorite relative to its impact pit. Limestone fragments ejected from the pit are enclosed within the broken line.

The fragments, of aggregate weight 23.27 kg, are in the collection of the Geology Department, School of Mines, Kalgoorlie. Reconstruction is almost complete, and the original weight of the mass was therefore close to 504 kilograms.

Field occurrence

Minor fragments (less than 20 g), major fragments, and the main mass were distributed in that general sequence from the impact pit (Figs. 2 and 3).

Figure 3.—Impact pit of the Haig meteorite partially excavated, looking north (compare with Figure 2). The vehicle (left of centre, near skyline) is at the site of the main mass; the small cairn (right, middle distance) is on the site of fragment 1 and the standing figures at the site of the other two large fragments. Most minor fragments were within the triangle formed by the pit, cairn and standing figure. Limestone fragments from the pit are less prominent than outcropping limestone and boulders, except in the area immediately beyond the pit.

The main mass was not seen in situ but must have lain much as it is now displayed in the Western Australian Museum (McCall and de Laeter 1965, Pl. VI A), and lightly embedded. Fragment 1, which is narrow and sharply keeled, had one end of the sharp edge embedded 16 cm into the soil, and much of its fracture surface had lost detail by rusting. The remaining fragments lay flatly on the surface or shallowly embedded.

In plan view, the impact pit has the shape of an isosceles triangle with blunted corners, and thus resembles the anterior face of the meteorite (Figs. 4 and 5), but the pit is more than four times larger in dimensions and higher in proportion to its base. The depth was 10 to 20 cm and the floor relatively flat except for a gentle transverse roll or shallowing approximately coincident with its widest part in a west-east direction (Fig. 10 F). The fill of angular limestone fragments (40 cm thick in the centre of the pit) graded in depth through fractured slabby limestone into bedrock. More than 1.6 m^3 of limestone fragments form a narrow, flame-shaped area of dispersion, the density of distribution declining rapidly from the pit; a similar volume of fragments remained within the pit.

Morphology of meteoritic material

Main mass.—This has dimensions 71.5 x 67 x 37 cm and the general shape of a bluntly tapered wedge which is widest where it is thinnest. Except on the weathered posterior face and the major fracture scars, the surface has a number of gentle rolls and hollows and well developed regmaglypts. The regmaglypts are polygonal, equidimensional, and 2-4 cm wide except in a pronounced zone of elongation and parallelism on the anterior face (Fig. 5)—where large individuals measure 9.1 x 3 cm and 7.6 x 5.1 cm—and in a less pronounced zone on the right-hand side of flight. The average length to width ratio of aligned regmaglypts on the anterior face is 2.0, but the effect is absent within hollows ("grouped regmaglypts").

Impact damage is present as scars, splayed or sheared corners and edges (including the rims of regmaglypts), from which small waves of metal are turned parallel to the general surface or even overturned. The directions of damage are thus indicated, and are confirmed by the disposition of undamaged hollows and the high points which shadowed them. The damage shows that the mass plunged into the ground with that face termed anterior directed forward (upward damage on apical face, steeply upward parallel to regmaglypts on right side, detachment of major fragments posteriorly in a direction normal to the anterior face as discussed below); it continued to move forward and to "dive" downward with the apex directed forward (outward shearing of entire edge of apical face, damage directed towards heel on right-hand side), at the same time rotating slightly anticlockwise (damage wrapping on to heel from right-hand side and directed to left of heel on anterior face); finally, it overturned (almost completely reversed damage on the leading right-hand face, the other faces shadowed or lifting).

The large scar on the left side (Fig. 7), has a rough angular surface except along its posterior margin, where there is a slightly concave, sheared fringe of variable width. Fragment 1 fits closely except along this fringe, where the concavities present on both main mass and fragment combine to form a gap opening posteriorly to 1.4 cm wide. Fragment 2 fits similarly on a small adjacent scar with a posterior gap 0.6 cm wide.

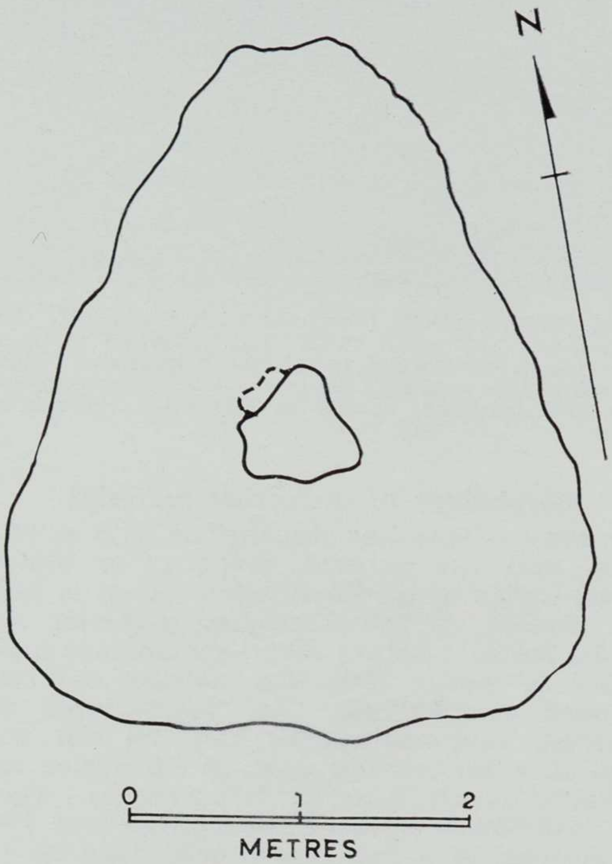

Figure 4.—Outline of Haig meteorite impact pit with superimposed outline of anterior face of the meteorite (face down). Fragment 1 is restored to position (broken line).

Major fragments.—Fragment 1 measures 30 x 23.5 x 14 cm and has the same surface features and directional damage as the adjoining areas of the main mass. Damage is severe on the anterior face and particularly on the outer edge which is splayed over in places as far as 15 millimetres. In restored position, this damaged edge is 7 cm above the general level of the anterior face and was thus its leading edge.

Fragment 2, of weight 163.1 g, is an irregular slab measuring 7 x 5 cm and about 1 cm thick. One face shows regmaglypts; the other has a pattern of equilateral triangles and angular projections, and is therefore octahedral. The marginal sheared fringe is represented by a small triangular area 1 cm wide at the base and showing the usual concavity. Fragment 3 of 38.1g is essentially similar except in its smaller size.

Minor fragments.—These show a variety of forms dependent on their origins.

(a) Five of the smallest, of weights 0.8-1.3 g, are thin and ragged, and may have a flattened and highly sheared face. They are deflected edges of the meteorite sheared to the point of detachment. The longitudinal section of one such fragment, cut perpendicular to the sheared face (Fig. 6) has a laminated structure resembling inverted, truncated, current bedding, and having some analogies with that structure in consisting of superimposed layers of stripped material, the meteorite and the earlier layers contributing to the later ones. The metal is finely granular and without trace of Widmanstätten texture.

(b) Eight fragments, of weights 0.6-15.8 g, have original surface except on a single sheared face. They appear to have been detached from upstanding edges as a result of one or two momentary blows rather than by a sustained shearing contact. Two of the fragments show also a partially exposed internal shear plane.

(c) Two thoroughly angular fragments of weights 0.9 g and 4.9 g have their shape defined by octahedral partings, and could have been plucked from the main fracture surface. A fragment of 3.6 g is similar except in having some original surface, and it could therefore have come from the anterior edge of the fracture surface. Likewise a fragment of 6.6 g with one sheared face, but otherwise octahedral, could have originated from the sheared fringe.

(d) A flattened fragment of 6.2 g has clearly been highly compressed. Both faces are strongly sheared and a third, internal, parallel shear is partially exposed. This is the type of fragment visualized as having been ejected from the notches along the posterior edges of the main fractures in a manner to be described below.

Fracture surfaces

Crystallographic interpretation.—The fracture scars show clearly the influence of Widmanstätten texture except on their sheared fringes. With few exceptions (resulting from distortion), the structure lines on the main scar (Fig. 7) comprise four sets in 45° relationship, and arise from fracturing generally parallel to a cube plane of the taenite, modified in detail by octahedral parting. The "north-south" and "west-east" lines of the central and flatter portion of the scar are the usual pattern for the cubic section of an octahedrite; the other less prominent lines, also at right angles and bisecting the angles between the first pair, are present only upon octahedral partings and are an equilateral triangular pattern projected upon the cube plane.

The ideal situation is shown with the same orientation in Figure 8. Octahedral planes

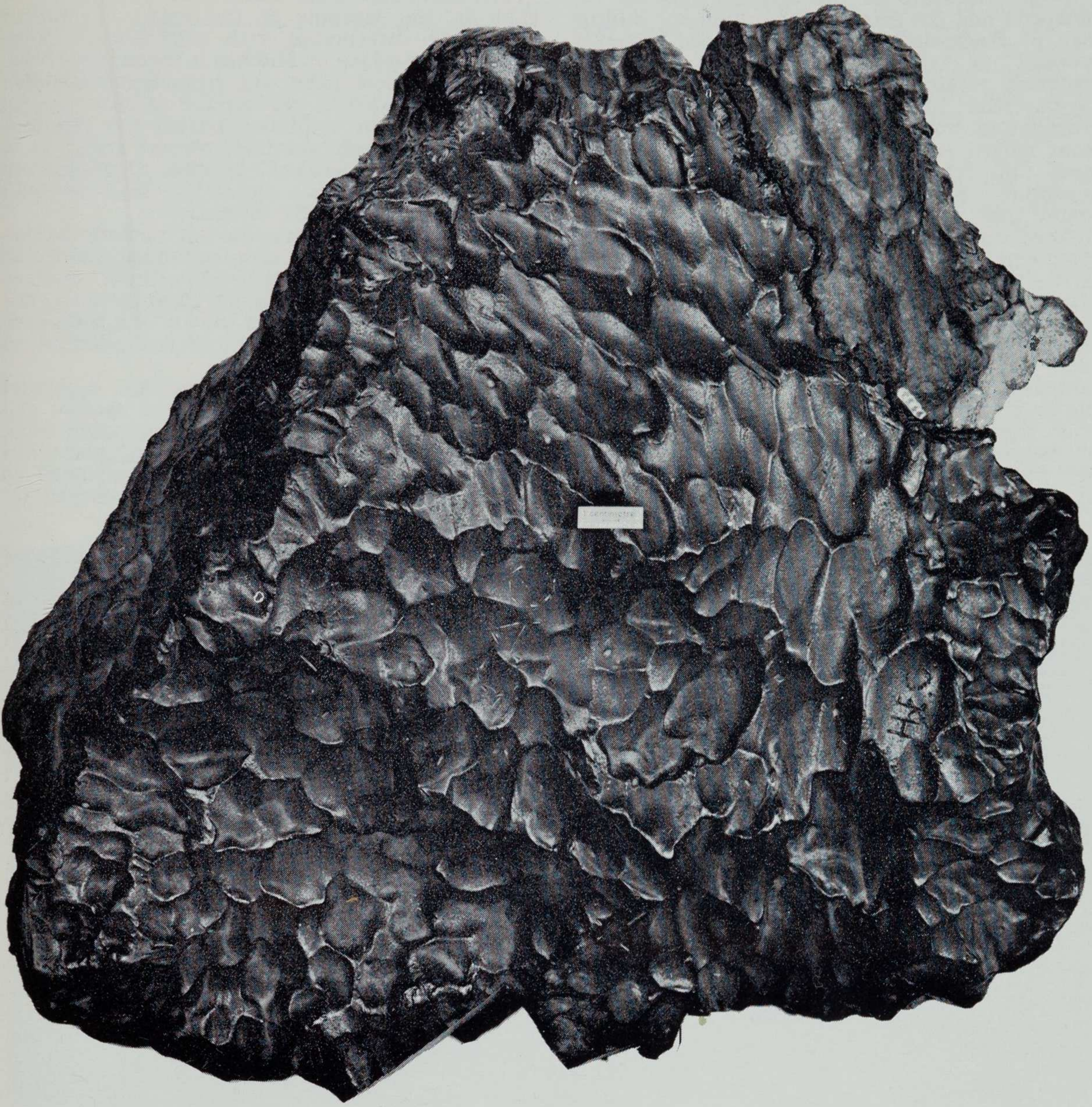

Figure 5.—Anterior face of the Haig meteorite with fragment 1 restored to position, apical end upward and heel at the bottom. The apex pointed in the direction of flight, and as this view is of the underside of the mass, the left hand side of flight is on the right of the figure and vice versa. Note severe impact damage on leading edge (top right).

appear on the cube face as lines parallel to the intersections of the two forms (the edges of the cube face); they appear on other octahedral faces as lines parallel to edges of the octahedron.

Small, square-based, pyramidal or wedge-shaped projections from the fracture surface were formed by octahedral parting and have the form of one half of an octahedron. Angular projections from the larger octahedral partings, such as the scar of fragment 2 (lower left of Fig. 7), have the form of equilateral-triangular pyramids, one parting being the base, the other three the faces.

Mechanical interpretation.—The rough angular area of the main fracture indicates brittle

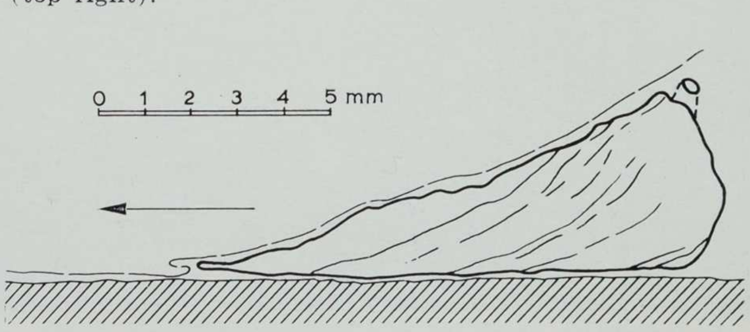

Figure 6.—Longitudinal section of a minor fragment of the Haig meteorite showing superimposed laminae of metal stripped from the meteorite and supposed relationship to the meteorite at the moment of detachment. The apparently isolated tip belongs to a curled layer not fully in the plane of the section.

tensional failure. As the anterior face of the meteorite met the ground, the prominent leading edge of fragment 1 would be hinged violently outward (a tensional effect), the detaching fragment retaining contact momentarily along its posterior hinge. Thereafter, the simplest explanation would be that the detaching fragment moved (relatively) upwards as both main mass and fragment plunged deeper into the limestone. Slickensides on the sheared fringes would then be in opposed directions and the sheared surfaces either relatively flat, or at least complementary in shape (Fig. 9A). The preferred explanation involves a combination of brittle and ductile behaviour in the manner of failure of a concrete beam (Fig. 9B). As a tensional fracture extends upward from the lower face, the neutral axis rises and compression is increasingly concentrated upon a rapidly shrinking area of cross-section. Material is "exploded" from the compressed hinge in a ductile manner of failure. The slickensides on both surfaces are then upward, and loss of material results in a notch.

The shearing on the main mass is upward but that on the margins of the major fragments cannot be interpreted with confidence. However, the existence of notches is incontrovertible, and the opposed sides, far from being complementary in shape, are almost mirror images (Fig. 9C). Their combined shapes are reminiscent of a line of greatest normal stress in a beam, and the "beaked" profiles of fragments 1 and 2 suggest that metal has been dragged upward and outwardly turned.

The two mechanisms are not entirely exclusive, but the relatively upward movement of the fragments probably occurred without contact being maintained at the hinge. Significantly, the shape of the pit resembles that of the meteorite more closely if fragment 1 is not restored to position (Fig. 4).

Localisation of the major fracture depended upon a fortuitous combination of factors including the downwardly projecting outer edge, the deep embayment in the side of the main mass (Fig. 5), and the smaller embayment at the apical end (now considerably enlarged by

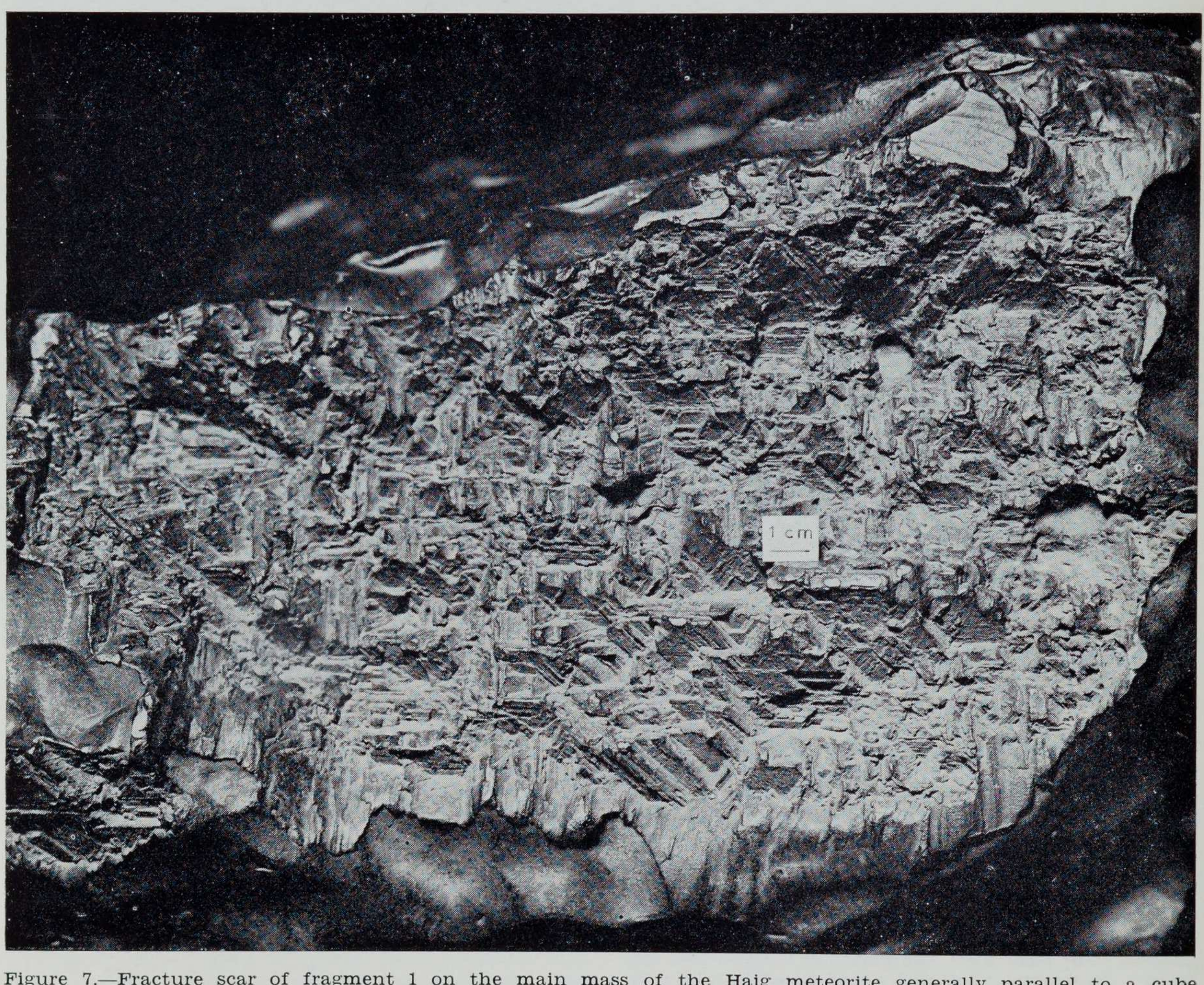

Figure 7.—Fracture scar of fragment 1 on the main mass of the Haig meteorite generally parallel to a cube plane of the taenite, but modified by octahedral parting. A concave, strongly sheared hinge area along the lower (posterior) margin. Two cavities resulting from loss of a nodular constituent towards upper right. The smaller scar of fragment 2 at extreme lower left has the pattern of equilateral triangles of an octahedral parting, here seen obliquely. A small fragment has been cut from the mass at top right.

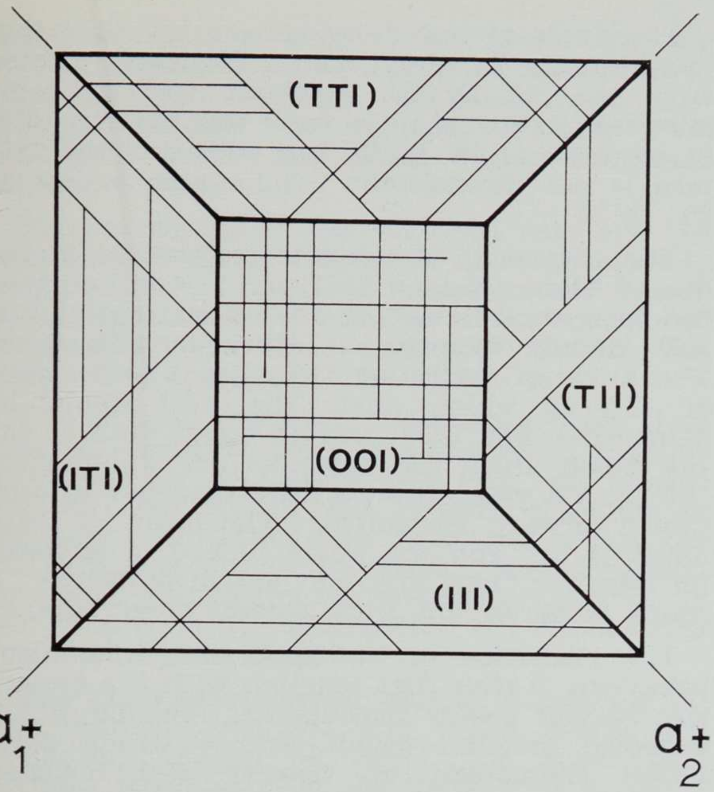

Figure 8.—View down the a_3-axis of a taenite octahedron modified by the cube face (001), showing the overall pattern of four sets of lines in 45° relation to each other resulting from octahedral sets of kamacite plates.

octahedral parting from fragment 1 and shearing on the main mass). Stress would be concentrated at such notches and they also made possible a short fracture path.

Aspects of the fall and fragmentation

Velocity.—A meteorite weighing 504 kg will reach terminal velocity within the earth's atmosphere and continue in free fall (Heide 1964, Tables 3-6). From data supplied, Dr. D. E. Gault (private communication) has calculated that the impact velocity would be of the order of 500 metres per second.

After impact, the main mass travelled on for a further 183 metres. The minimum velocity requirement is 42 m/s for a single arc of flight of 45° elevation. For flatter angles (or for the complementary, but unlikely steeper angles) higher velocities are necessary, but at flatter angles there is increased probability that the mass would ricochet or bounce and roll. Thus, for example, a velocity of 60 m/s is needed for a flight of 10° elevation and two-thirds distance, but the mass would probably continue on for the full distance. It is likely that the velocity immediately after leaving the pit need not have exceeded 60 metres per second.

If the velocity was reduced from 500 m/s to 60 m/s at the pit, more than 98% of the kinetic energy was consumed. Even if the interval between the velocities is drastically narrowed by halving the one velocity and doubling the other, the figure is still greater than 75%. This is consistent with the observation that damage to the meteorite is explainable in terms of a single event, and that no ground damage other than the pit was detected.

Orientation.—For purposes of discussion, an arbitrary angle of trajectory of 45° is used (Fig. 10A-F).

Orientations with the centre of mass above the fulcrum provided by the apex of the mass may be disregarded. Cases A and B tend to penetration rather than rebound unless the angle of trajectory is improbably low; neither are the major fragments detached in a direction normal to the anterior face ("hinges" are parallel to the anterior face). In case C, the fragments might be correctly detached but only at high trajectory where there is no tendency to continued forward movement. Case D is favoured because it could result in a "heel and toe" action which fits the sequence of events deduced from impact damage, provides a possible explanation for the shallow transverse roll in the floor of the pit, and at the same time could give the mass a forward velocity. The shape of the mass is ideally suited because of the wide bearing surface at the base of the anterior face and the relative narrowness of the apical end. As the anterior face moved forward into a horizontal position, the major fragments

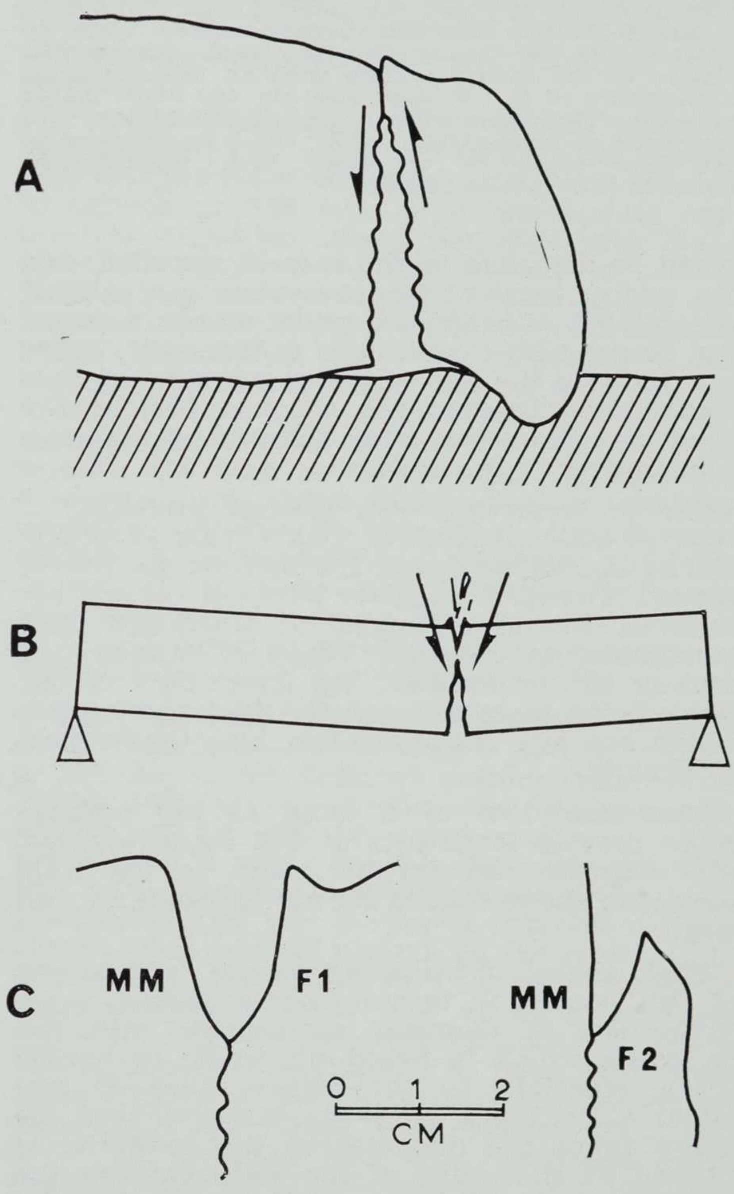

Figure 9. A.—Profile of portion of apical end of Haig meteorite with fragment 1 in course of detachment in a brittle manner. B.—Failure of beam, showing upward development of tension crack and ductile behaviour with ejection of material from the compressed hinge area. C.—Profiles of notches at posterior (hinge) margins of fragments 1 and 2, the main mass in each case on the left.

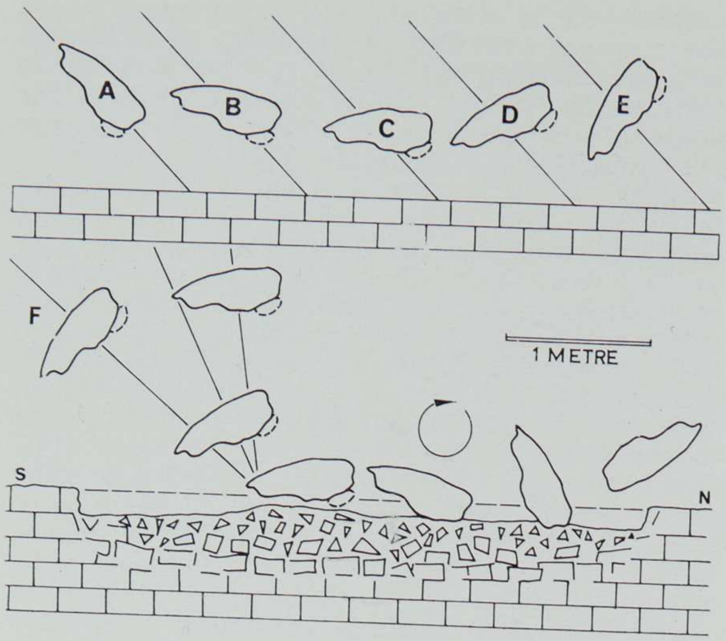

Figure 10.—Profiles of the Haig meteorite seen from the right hand side of flight, the anterior edge of fragment 1 (detached from the side distant to the observor) indicated by the broken line. A. to E.—Orientations relative to the earth's surface with an arbitary angle of trajectory of 45°. F.—Left and top, the limits placed on angle of trajectory when line of flight coincides with elongation of regmaglypts; below, the favoured orientation and angle of trajectory with diagrammatic sequence of events at impact.

would be detached in the correct direction, and the main mass, now presenting an almost streamlined appearance, could plunge forward and deeper whilst continuing to turn over. There is a limit to the heel and toe action; case E is inadmissible because the extreme heel of the mass was shadowed from damage by the high point nearer to the apex.

Angle of trajectory.—On general principles it appears quite anomalous that a mass of nearly 500 kg should be found 183 m from its site of impact. The attainment of terminal velocity results in the steep angles of trajectory least favourable to ricochet (reported angles are usually 60° or greater, the lower part of the range being more common for the larger masses which are less readily drawn into the vertical by gravity).

The disruption of a mass at low altitude could provide fragments of flat trajectory, but the complete regmaglyptic relief on the Haig meteorite shows that it did not originate in that way.

High angles of trajectory usually lead to one of two results: in unconsolidated ground, a pit is formed, of diameter comparable with the meteorite which is found within it; in harder rocks, especially in the higher range of terminal velocities, a bowl- or funnel-shaped pit many times the diameter of the meteorite is formed by shattering of the meteorite and the ground, and is lined and surrounded by meteorite and rock fragments. Cases of rebound from pits are sufficiently rare to be remarked: two irons of the Sikhote-Alin shower weighing 135 and 300 kg were found 2.5 and 5.5 m from their pits (Krinov 1961, p.86), but the distance here involved is clearly of a different order.

The angle of trajectory can be judged within broad limits by the pattern of debris ejected from the pit. Dr. D. E. Gault (private communication) would infer from this pattern (Fig. 2) an angle of 40° to 50° but adds that the pattern is not inconsistent with angles as low as 20° to 30°.

The alignment of elongate regmaglyps in the line of flight (Krinov 1961, p.251) can be satisfied in a general way by the orientation of Fig. 10D already adopted on other considerations. The angle of trajectory then has a lower limit of 42°—at which angle the heel would be damaged—(Fig. 10F), and an upper limit of 80° (at which angle the anterior face would meet the ground squarely with little tendency to continued forward movement). The mean of these limits is 61° and the angle judged most likely for effective "heel and toe" action is 60°-70°, a result in agreement with general observation.

The resolution of the apparently anomalous behaviour is thus that reaction with the ground was neither purely ricochet nor rebound, but a deflected rebound which gave a strong horizontal component of velocity and focussed material low as in impacts at low trajectory.

Impact pit.—The pit does not fit into any well established category but an explanation can be offered for the distribution of the meteoritic material and limestone fragments. It is suggested that the pit resulted from a shock wave, perhaps with the decompression more or less simultaneous with the meteorite leaving the pit.

The work accomplished in damage to the meteorite, shattering of ground, and continued travel of fragments, is so great that it is of interest to contrast the case of the recently discovered Mundrabilla irons 120 miles to the east-north-east upon the same limestone, and for which no evidence of cratering or bouncing was found (Wilson & Cooney 1967). Except in scale, there are close analogies between the materials; the smaller Mundrabilla iron is a fragment of a larger one found 200 yd distant; they were accompanied by numerous fragments scattered over a wide area (compare main mass, fragment 1 and smaller fragments of Haig). The large Mundrabilla mass (op. cit. Fig. 1) and the main mass of Haig (McCall & de Laeter 1965, Pl. VI A) have the same bluntly wedged shape, and as figured with their fracture scars towards the observer, are nearly mirror images.

It is cautiously suggested, and with deference to the authors, that an impact pit, possibly shallow and inconspicious, might be sought near the limits of distribution of the smaller fragments.

Summary.—The Haig meteorite approached the earth's surface with a velocity of about 500 m/s and at an angle of about 65°, a large triangular face towards the ground, its apex upward and forward in the line of flight. First contact was made with the ground near the broad base of the anterior face, causing the mass to tilt forward until the downwardly propecting left front edge met the ground and was hinged violently outward. Two smaller fragments were similarly detached, and minor fragments were broken from the anterior edge of the major fracture by octahedral parting of the metal, were plucked from the major fracture, "exploded" from compressed posterior hinges and sheared from prominent points and edges during continued forward movement.

The embedding of the left front edge and the resistance of major fragments to detachment in combination with forward movement resulted in a slight anticlockwise rotation so that continued overturning by "heel and toe" action was deflected to the left of the original path.

The impact shattered thoroughly more than 3 m^3 of limestone, more by shock effect than by direct contact, and about half of it was ejected and focussed low by the forward slumping of the mass; the other half remained within the pit with a record of the impact moulded upon its surface. Insignificant meteoritic material (a few grams with dimensions in millimetres) remained within the pit.

The main mass turned over as it left the pit and probably bounded and rolled during the remaining 183 m of travel, the latter part perhaps irregularly, in the manner of a rolling plate losing velocity.

The axis of the pit and the displaced limestone is directed 10° east of north and is the likely line of flight, but the axis of the sector containing all except a few minor fragments of meteorite is directed due north. The main mass was found only 18 m from the latter axis, a distance not difficult to explain by irregularities of the path, but it was 50 m from the axis of the pit, a distance less readily understandable unless a deflection of 10° occurred during impact.

The largest fragment, with the resultant velocity of forward movement and violent hinging to the right, crossed the flight path of the main mass. Most of the other fragments were scattered within the sector of a circle of angle 35° and radius of 75 metres.

Notes on mineralogy

The mineralogy has been examined only in a slice cut from the heel of the mass (Fig. 5), and thus partially bounded by anterior and posterior faces of the meteorite. Widmanstätten texture is present except in an aerodynamically heated and recrystallized rim adjoining original surface.

Interior.—The approximate true width of kamacite plates, determined by the method of Frost (1965b) is 0.9 mm; the meteorite is therefore a medium octahedrite. Kamacite occurs within the plates as polyhedral grains up to 2 mm across. Taenite selvages have apparent widths 0—0.3 mm, commonly 0.01 mm. The plessite is of both granular and lamellar types. Where seen in relation to each other the boundary of granular plessite, the lamellae of plessite (0.05-0.1 mm wide), and full-scale kamacite bars are parallel and show no textural transition.

The percentages by volume of the metallic constituents, estimated with a Leitz integrating stage by traverses on both sides of the slice are:

	%
Kamacite	85.1
Taenite	1.0
Plessite	13.9

Troilite occurs within kamacite as nodules not commonly exceedng 0.2 mm diameter, in veinlets, and in association with an unidentified mineral; its distribution was confirmed by sulphur prints. Two large nodules lost from the major fracture surface (the larger 1.8 cm diameter), and those represented by small pits on original surface may also have been troilite.

An unidentified mineral is present as a single, dark, hard, lath-shaped crystal measuring 3.0 x 0.4 millimetres. It is enclosed within two adjoining grains of kamacite and contains a few small inclusions, probably of metal. Troilite nodules are present at its ends and sporadically along its edges. The writer was unable to identify this mineral and the additional observations made by Dr. George Baker were also inconclusive. A spectrochemical analysis made by Mr. T. H. Donnelly showed strong lines of silicon. An electron probe microanalysis is to be made.

Thermally altered rim.—The minutely granular heat-affected rim along the edge with greater regmaglyptic relief varies in width from 0.6 mm in hollows to 2.35 mm at an upstanding regmaglypt boundary; along the edge with lower relief the width varies from 1.6 mm in hollows to 3.7 mm on a convex curve. The rim is thus distinctly wider on the posterior than on the anterior edge. Weathering has not affected either face severely in this part of the meteorite. Such greater widths on the posterior face are not unusual when metal ablated from an anterior surface has been redeposited on the posterior (Lovering and others 1960), but no ablation deposit is present in this case. Indeed, relic texture is recognisable throughout the rim because of the persistance of taenite (including that taenite which has a characteristic texture as a component of plessite) after the complete recrystallization of the kamacite.

Comparison with Duketon.—The nickel contents of the Haig meteorite (McCall & de Laeter 1965, p. 35) and of the Duketon medium octahedrite (Frost 1965 a) are similar and the kamacite widths are 0.9 and 1.0 mm respectively. The comparison is made because these are the only two of 30 Western Australian irons which have a complete and well developed cover of regmaglypts. The subdued pattern on the reverse side of Duketon (Frost 1958, Pl. I) is very similar to that on the posterior face of Haig, but the extent to which weathering has contributed to this similarity is unknown; in both cases such relief may be in part a primary feature (compare the Cabin Creek iron—Mason 1962, Fig. 21). The Duketon iron was found 340 miles distant from Haig, but dispersal over comparable or even greater distances has been proposed for groups of hexahedrite irons (Mason op. cit. p. 133), in which the relative rarity of the type is an argument favouring a common origin of the individuals. The argument is not valid in this case but the possibility of relationship is worthy of investigation.

THE MOUNT EGERTON METEORITE

Introduction

The Mount Egerton meteorite was discovered in 1941, but the few fragments received into official collections were apparently lost until investigations made in recent years led to their partial relocation (McCall 1965). The precise site of find remained unknown and the only remaining link with the original discovery was the aged aborigine, Sandy Gaffney.

Mr. A. E. Bain, manager of Mount Clere pastoral station, twice brought Gaffney to the station to indicate the general area of find and to make searches. The site was rediscovered by M. K. Quartermaine and A. E. Bain in 1966, and more than 3000 fragments of aggregate weight 19.0 kg were collected. Dr. Brian Mason and Dr. E. P. Henderson later recovered a further 8 kg, principally small metallic fragments located with the aid of a mine detector. At least 0.64 kg had been previously recovered in 1941; a reputed quantity of 3.7 kg included in that recovery (unpublished laboratory report quoted by McCall 1965, p. 248) is surely a typographical error, as the described fragments total 379 g (Anon 1944). The total recovery is therefore at least 27.6 kilograms.

The site is 2.4 miles in direction 26° from Mount Egerton No. 3 Well (Fig. 11) and has approximate coordinates 24° 53′S., 117° 38′E.

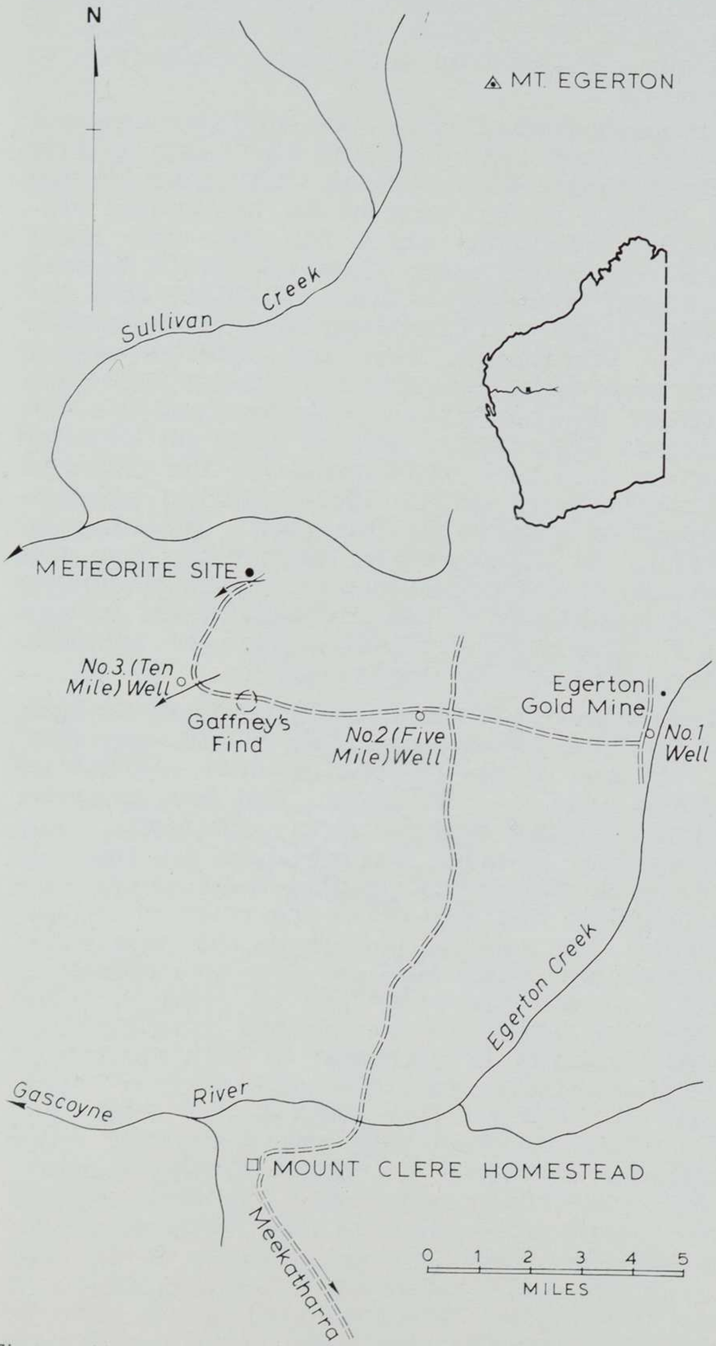

Figure 11.—Sketch map showing site of find of the Mount Egerton meteorite.

Field occurrence

Meteorite fragments were abundant near Pit 1 (Fig. 12), the impact pit discovered and excavated in 1941, and near the unexcavated Pit 2. These two concentrations contained more than half of the 19 kg collected by Messrs. Bain and Quartermaine. The 8 kg collected by Dr. Mason and Dr. Henderson came from "around the main hole", in a "fan-shaped area extending 15-20 yd downhill" and "from around the base of a clump of small bushes" (Pit 2), and therefore had the same general distribution. A compact group of five fragments found 18 m from any others represents a third small original mass. The 1941 recovery presumably came from about the excavated pit.

The general direction of flight is inferred to have been easterly, which supports the opinion of Dr. G. J. H. McCall (private communication) that the fireball widely observed to be travelling west-south-west in this district in 1940 was unrelated to the Mount Egerton meteorite first recovered in 1941.

Pit 2 is slightly dished, about 0.6 m in diameter, and in the shelter of a clump of small bushes, a situation much favoured by some ground-dwelling birds. It was free of large stones and overlain by many small and roughly sized pieces of meteoritic enstatite and nickel-iron. The finders regarded it as a bird's nest, but it can be adequately explained as a weather-beaten impact pit. Surface stones would be scattered at the moment of impact, and small pieces of meteorite would remain on the surface as subsequent rain and weather caused the finer material to settle.

The meteoritic material

Textural features.—In bulk, the materal resembles a disintegrated coarse-grained pegmatite, the predominant, well-cleaved enstatite resembling feldspar. Only the occasional coarser-grained metallic segregations attract attention, and it is understandable that only metallic fragments were forwarded to the School of Mines for identification in 1941. The enstatite is of two types, the clear glassy type occurring in vein-like manner within the white type. Fragments illustrate a complete range of proportions of enstatite and metal (Fig. 13), but stony fragments, many of them enstatite cleavage fragments, predominate.

Enstatite grains attain large size. The largest fragment measuring 8.3 x 4 x 3.6 cm, consists of portions of two slightly divergent enstatite grains and some metal (Fig. 13 B); the largest cleavage fragment, measuring 6.7 x 3.4 x 2 cm and weighing 58.9 g, is a rough 45° isosceles triangle in cross section; the original grain could therefore have had at least twice the cross sectional area and weight.

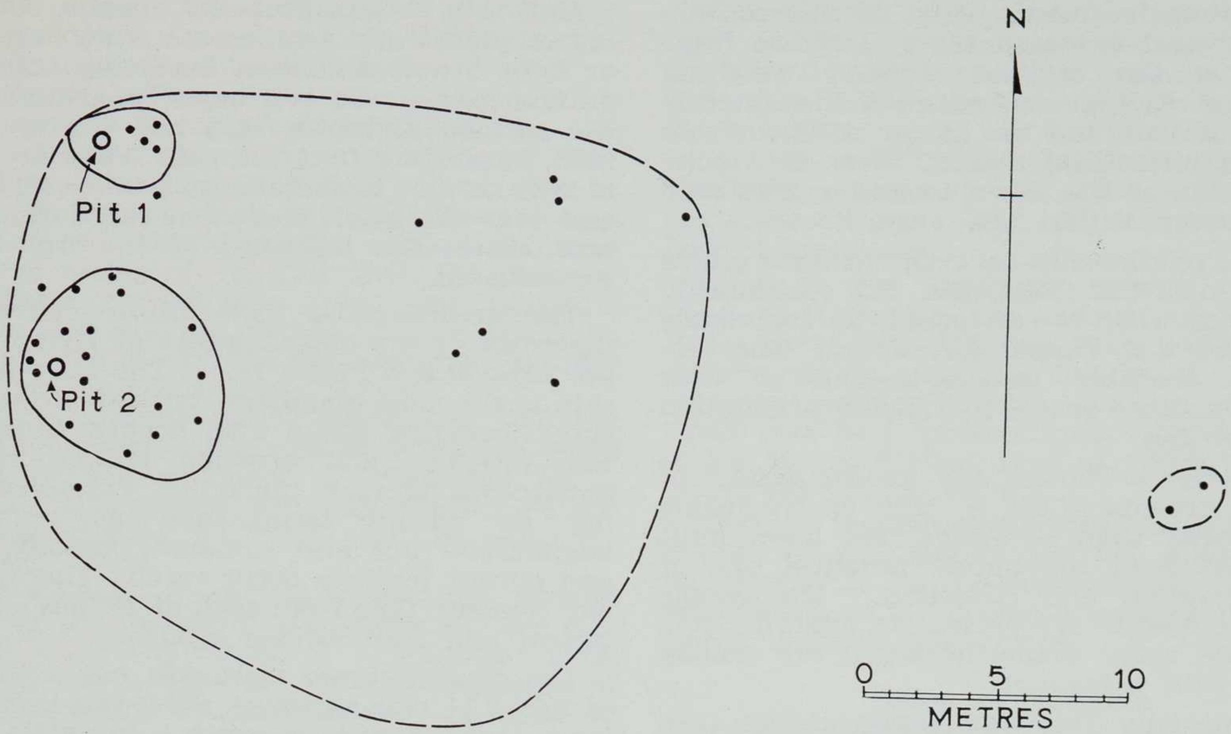

Figure 12.—Field distribution of the Mount Egerton meteorite fragments. Areas containing more than 100g/m^2 enclosed by firm lines; the remaining fragments were within the broken lines. Fragments weighing more than 40 grams indicated by dots (a further five such fragments from the 1941 recovery were probably from the vicinity of Pit 1).

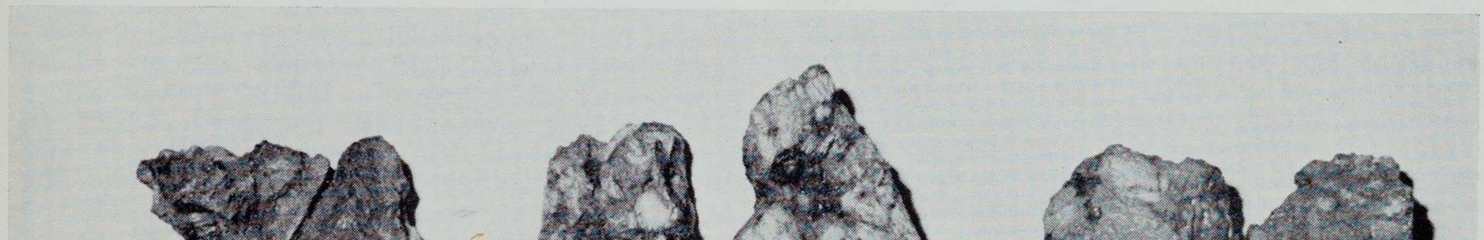

Figure 13.—Types of impact fragments of the Mount Egerton meteorite. A.—Nickel-iron with some adhering and enclosed enstatite; two fitting fragments at right shown slightly separated. B.—Enstatite with coarse grains of metal. C.—Enstatite with finer grains of metal. D.—Type without macroscopic metal. E.—Enstatite cleavage fragments, one showing melt skin over regmaglypt at its upper end. F.—Fragments showing areas of dark melt skin over regmaglypts. Scale in centimetres.

Two fitting fragments (Fig. 13 A) contain metal estimated to weigh 160 g, and two fragments from the original recovery weighing 121.7 g and 83.9 g were described as mainly metallic (McCall and de Laeter 1965). From such large interstitial masses there is a continuous range of size down to grains seen only microscopically within the enstatite.

Textural relationship between enstatite grains can be seen in few fragments. The relationship varies from slightly divergent to completely right-angled with partial penetration. The texture was probably igneous-looking or with elongate enstatite grains in random orientation as in a hornfels.

Fragmentation.—Though the known weight of meteorite exceeds 27,000 g, only 22 fragments are of greater than 50 grams. The lower limit of size has been the purely practical one of field observation and collection. Microscopic grains of enstatite are present in adhering soil, and minute rusty grains of metal are readily collected with a magnet.

The unusually thorough fragmentation can be ascribed to the coarse grain and ready cleavability of the enstatite coupled with the rocky nature of the site.

A prior history of mechanical deformation also provided surfaces along which fracture occurred. Many fragments have areas of hummocky or smoothly dished surface, the latter somewhat resembling regmaglypts but having higher relief. These forms arise from breakage along the contact of the two principal textural types of enstatite. "Veins" of the glassy form may pinch and swell providing either a hummocky surface or its negative equivalent. Microscopically, the clear enstatite show various degrees of strain by multiple twinning, strain shadows, cracking and dislocation. The other type is minutely granulated and neither extinguishes cleanly nor shows the aggregate effect resulting from randomly oriented grains. Instead, strain shadows move across numerous grains in optical continuity, and in parallel bands may move in opposite directions. The material appears to be multiple twinned and shattered by some process which permitted very little rotation of individual grains. There are other textural variants and a variety of boundary relationships. These textures may be the result of a severe shock wave with complex internal reflections.

Original surface features.—Patches of melt skin of up to 4 cm^2 are present on nearly 200 fragments. Occasionally, it is present on two or three sides, suggesting that the fragment was an upstanding part of an irregular surface; in no case is the coverage of skin sufficiently extensive to suggest individuality in atmospheric flight.

The skin commonly overlies regmaglyptic surface, usually portion of a single regmaglypt, rarely three to five. Most regmaglypts are 1 cm or less across with smooth bounding ridges, but a complete oval example measures 2.0 x 1.1 cm and an incomplete one is 2.3 x 2.0 x 0.7 cm deep.

Melt skin is dark grey and opaque, but merging in places into small areas which are brown or light brown and then becoming translucent or transparent. In two cases, a grain beneath the surface of brown skin has a grey opaque halo, suggesting that the pale transparent skin is that normal to the almost iron-free enstatite, and that the much more general, dark, opaque skin shows the influence of the iron-bearing constituents.

The textures of the melt skin are conveniently described in the nomenclature of Krinov (1961, pp. 265-270 and Plates 1-7). The close-textured skin is the most abundant, but the striated texture (including striae with hooked ends, terminal droplets, and crossing striae) and the scoriaceous texture (including examples showing its abrupt termination at regmaglypt boundaries) are also common; knobby, ribbed and porous textures occur rarely. There is thus one common type from each of Krinov's frontal, lateral and rear surface groups.

The close-textured melt skin has a thickness of 0.05-0.11 mm and may show two layers. The inner layer of uniform width is minutely fibrous and orientated more or less normal to the meteorite surface. It appears to represent the first stages of melting extending down the structure of the enstatite. The outer layer, of variable thickness, is glass showing incipient devitrification.

The scoriaceous skin has a thickness up to 0.25 mm and may show three layers, the inner two as for the close-textured skin and the outermost scoriaceous and opaque except where thinned by the presence of bubble cavities where it shows a hematite red by transmitted light. In a typical section, the fibrous layer is 0.03 mm thick, the structureless layer 0.06 mm and the scoriaceous 0.12 mm thick. Because of the similarity of the inner layers to those of the close-textured skin, including the irregular thickness of the second layer, it appears that the scoriaceous layer has flowed over an existing close-textured skin. Volatiles from troilite and schreibersite during their incorporation in the melt may account for the mobility of the material and for its vesiculation.

Short irregular cracks which are sub-parallel to the meteorite surfaces are developed sporadically in a zone about 2 mm thick immediately beneath the melt skin, and are regarded as an exfoliation effect in advance of melting.

Specific gravity.—The specific gravity of the meteorite is important as providing a means of assessing the proportions of the two major constituents; subsequent detailed work can then be integrated into a general analysis or a mode. Because of the extreme variability of the fragments both in size and mineralogical proportions, the whole of the available material was bulked, thoroughly mixed by rolling, coned and quartered several times to provide samples of rather more than 1 kg each. The specific gravities of one sample from each of the final splittings were determined by using a large flask fitted as a pycnometer. The results were in the range 3.50-3.79 with a weighted mean of 3.64. That the range of values represented a true variation related to the difficulties of sampling such a mixture of sizes and types was demonstrated by reproducibility of results.

Metal content.—The specific gravities of a number of metallic fragments of weights 3-13 g and free of adhering silicate were in the range 7.05-7.66. The variation is greater than can be accounted for by included schreibersite and troilite or by a slightly rusted surface. Included silicate is indicated (McCall 1965, Fig. 6), and the highest reproducible value was therefore accepted. The specific gravity of pure $Mg\ Si\ O_3$ (to which the Mount Egerton material approximates very closely) is 3.20±0.01.

Using the specific gravity values 3.64, 7.66 and 3.20 for meteorite, metal and enstatite, the metal content of the meteorite is calculated to be 21.0% by weight and 9.9% by volume, or for practical purposes, one fifth and one tenth respectively.

Size of masses.—From the weight and specific gravity of the meteorite, the fragments are calculated to be equivalent to a spherical mass nearly 30 cm in diameter, or to two masses of about 17 cm and 27 cm diameter (apportioned according to the weights of material closely associated with Pits 1 and 2 respectively).

Discussion

The Mount Egerton meteorite closely resembles Shallowater, which is usually classed with the enstatite achondrites, though containing 12% of metal plus troilite (Mount Egerton 21%). Both have features common to, and intermediate between those of the enstatite chondrites and the enstatite achondrites which have been claimed to have been derived from them (Lovering 1962; Ringwood 1962; Morgan and Lovering 1964). A comparison is made in Table 1 drawing principally upon the work of Foshag (1940), McCall (1965) and Mason (1966).

The essential mineralogy is a nearly iron-free form of $Mg\ Si\ O_3$, and metal containing about 6% nickel (often showing evidence of strong reduction in the presence of silicon or perryite), the amount of metal and troilite declining to the achondrite end. Texturally, Mount Egerton and Shallowater resemble the achondrites in their coarseness of grain, and the chondrites in their lack of brecciation.

There is also similarity between the metal phase of Mount Egerton and the small (0.57 kg) Horse Creek iron (McCall 1965, p.243), both of which contain perryite. Dr. E. P. Henderson (private communication) suggests that Horse Creek may be a metallic mass from a meteorite of the Mount Egerton type, of which the silicate phase was not recovered.

The new recoveries will make possible detailed studies of the Mount Egerton meteorite, but tentatively it is conveniently grouped with Shallowater as an unusually metal-rich, unbrecciated, enstatite achondrite.

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TABLE 1

Textures and mineralogy of enstatite-rich meteorites

	Enstatite chondrites (15)	Mount Egerton	Shallowater	Enstatite achondrites (8)
Texture and Structure	Chondritic to finely granular (when recrystallized) with small metal grains evenly distributed Usually unbrecciated	Extremely coarse-grained enstatite with coarse to fine interstitial metal and some included fine grains Incipient brecciation (Shock induced?)	Very coarse-grained enstatite with small grains of included and interstitial metal Unbrecciated	Coarse-grained enstatite, accessory metal Thoroughly brecciated
Dominant silicate	Almost iron-free clino-enstatite (in chondritic type) and/or enstatite (in recrystallized type)	Almost iron-free enstatite	Almost iron-free enstatite	Almost iron-free enstatite Occasional accessory-clino-enstatite
Accessory silicates	A silica mineral in chondritic members, oligoclase in recrystallized ones	None recorded	Oligoclase 2 % Olivine 5 %	Oligoclase and Olivine sometimes present
Nickel-iron. Weight%	19 to 28 %	21 % (including troilite and other accessories)	9 %	Accessory
Triolite. Weight %	7 to 15 %		3 % (includes other accessories)	Accessory
Nickel content of metal	c. 6 %	6.38 %	6.83 %	c. 6 %
Schreibersite	Often accessory	Present	Vivianite (weathering of schreibersite?)	Known in accessory amount

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